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EXPERIMENTAL INVESTIGATION OF A COMBINED SOLAR PARABOLIC DISH AND TROUGH COLLECTOR FOR WAX MELTING APPLICATION

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ABSTRACT

The increased cost of electrical energy which depletes conventional resources promotes switching over to renewable solar technology. An experimental study of a simple parabolic dish and trough solar collector combination is tested under Chennai weather condition aimed at attracting users rapidly. The set up for domestic wax melting application using pumped water, is described showing the performance. The reflector and receiver were fabricated from polished aluminium sheet and copper respectively. Experimental results showed that the overall performance of the combined parabolic collectors is satisfactory, since the higher temperature of heat transfer fluid is achieved.

KEYWORDS: Electrical Energy, Experimental Results & Fluid is Achieved

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Original Article

INTRODUCTION

Higher the carbon release, greater the hydrocarbon diminishment and results in climate crisis globally. It broadens distinct separating disparity amongst power developed and desired. Eco-friendly renewable resources demand realization of imminent origination of energy. Solar radiation being a generous and bountiful asset it gained momentum in extensive applications. To attain sustainable energy territory solar radiant energy is very important. A huge share of global energy requirement like industrial heat, space, water heating, desalination and electric power generation can be met in an encouraging approach with the usage of Solar energy. [1-8].

A solar collector is a heat exchanger that converts radiant solar energy into heat. In essence, this consists of a receiver that absorbs the solar radiation and then transfers the thermal energy to a heat transfer fluid (HTF), such as water or air. Because of the nature of the radiant energy as well as the types of applications for which solar thermal energy can be used, the design and analysis of solar collectors present an unique and unconventional problems in heat transfer, optics and material science. Solar energy nature refers to spectral characteristics, its diurnal and seasonal variability, changes in diffuse to global fraction, etc,. This heat can be used for heating water. The heart of a solar collector is the absorber. The main classifiction of solar collector is made either of working fluid water/air/oil or solar receivers of tracking /non tracking types. The air collector may operate at a higher temperature than a liquid-filled collector, resulting in greater thermal losses and, consequently, a lower efficiency. The choice of the working fluid is usually dictated by the application. For example, air collectors are suitable for space heating and convective drying applications, while liquid collectors are the obvious choice for domestic and industrial hot-water applications. In certain high-temperature applications, special types of oils are used that provide better heat transfer characteristics. The fluid for heat transfer flows through a heat conducting pipe,

connected to the absorber.

Modern life style at reduced costs is the main advantage of solar collectors[9]. The concentrating collector usually employs parabolic/ concave mirrors/reflectors to concentrate the total solar energy incident on the collector surface. The larger collector surface is necessary for high temperature achievement. Some of the collectors in this category are a parabolic trough collector (PTC), compound parabolic concentrator (CPC), parabolic dish, and cylindrical parabolic concentrator.

The effective sunshine occurs maximum 6 hours per day and since heating and hot water loads occur whole day, Some type of energy storage system is needed when using the solar energy[10].

Solar spoon collector is a simple solar thermal application that converts solar rays into heat which is in turn used for wax melting, water heating and cooking, etc. It insists in saving electricity and stoping usage of fossil fuels to avoid harmful emissions, by the usage of never depleting solar energy as an alternative. In this work, two types of vessels were used - a water vessel and a wax vessel. Heat absorbed by water from the absorber of dish collector and heated water flows through the pipe, that heat was maintained at a stable temperature in the pipe by the trough collector. The Heated water then flows through the pipe attached to the outer area of the wax vessel. The phenomenon of heat conduction takes place inside the vessel, ensuring the heat is transferred through from the outer area to inner area of the wax vessel. The heat transferred to the vessel is effectively used in melting the wax. The Water is recirculated again to the dish collector by using recirculation pump.

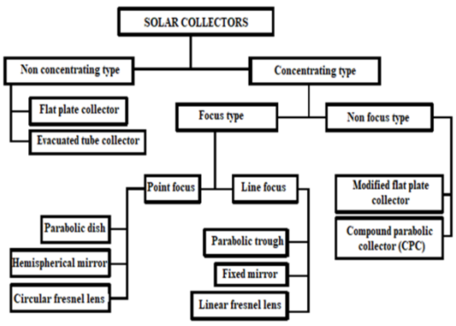

Figure 1 : Types of Solar Collectors Figure 2 : Actual Experimental Set Up

SOLAR COLLECTORS

The various types of collectors are shown in figure 1. A combination of parabolic dish collector and solar trough collector is proposed for the opted utilization of melting wax for making candles by the solar radiant heat. The parabolic dish collector is the most powerful type. It can concentrate solar energy at a single focal point. A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished aluminium mirror. A copper tube runs along the length of the trough at its focal line. The mirror orientation is such that the sunlight is concentrated on the tube, which contains a heat transfer fluid on heating attains a high temperature. Dish collector is a point concentrator and trough collector is line concentrator. This setup was used for melting wax by using water as heat transfer fluid. Dish collector heats the water enough to the required temperature and Trough collector maintains the stability of the heat in the pipe. Thus heat losses got reduced. Parabolic trough collectors establish a prominent and mature solar thermal appliance for industrial process heat, power generation and many more. (11,12). The mechanisms of analyzing their optical and thermal achievement are also elaborated. A competitive economical trough

collector, with North–South axis in horizontal E-W tracking developed and tested showing increased efficiency. Negligible shadowing effects are detected (13). Parabolic trough collector has been examined, analyzed and tested with different type of reflectors. Aluminium sheet was identified as cost effective material to use as a reflector (14).

The powerful changeovers of solar radiation into heat for higher thermal gradients are possible with the use of concentrating solar collectors. Their characteristics with a variety of utilities like water heating and steam generation(15,16). Small-sized trough collectors work a little better when experiments at multiple flow rates conducted,in the south-facing than the tracking mode(17). A sheet of aluminium covered on the parabolic steel back support with 90° rim angle presented well working (18).

A lightweight parabolic trough collector for industrial heating applications performed with an aluminium receiver and a constant flow rate of HTF(19). An evacuated tube solar collector coupled with Parabolic Trough was trying to heat water instantly and succeeded to reach a maximum temperature of 60°C(20).Upon conducting experiments with different receivers of trough collector, porous disc receiver shown performance improvement (21).

EXPERIMENTAL SETUP

The experimental setup consists of Parabolic dish collector, Water vessel or absorber, Parabolic trough collector, beam collector (Copper tube), wax vessel, recirculation motor, return line and thermocouples. The actual and schematic of experimental setup are shown in figure 2 and figure 3 respectively.

Parabolic dish collector is a point concentrator and its bottom layer is made up of acrylic sheet. The aluminium foil sheet is stuck over the acrylic dish plate for focusing the sun rays into a single point. Acrylic sheet to absorb the heat and aluminium cover to reflect the radiation to heat the water enough of needed temperature. A water vessel or absorber stores the hot water and to receive heat from a dish collector made up of copper. Parabolic trough collector is a line concentrator and it is made up of an acrylic sheet with aluminium cover. This is used to make the hot water stable with the temperature of the dish collector to wax vessel in a pipe or line receiver.

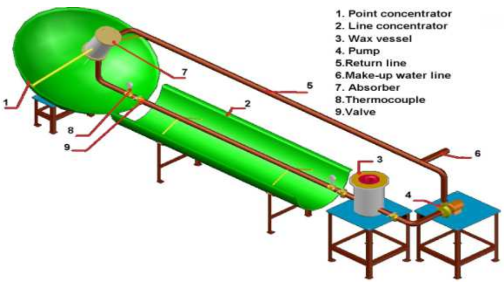

Figure 3: Schematic of Combined Solar Collectors for Melting Wax Using Water as Heat Transfer Fluid

The copper pipe is connected to the beam collector and receiver tank which is placed at the focal point of the dish collector. It is used for flow of the hot water from water vessel to wax vessel. There is instability of heat due to the radiation loss, received from trough collector. The pipe is made up of copper and insulated in the return line. Wax vessel is a cylindrical cup of copper used for melting the wax. Recirculation Pump functions by a D.C. motor with 12 V for recirculation of hot water again from wax vessel to dish collector. K type thermocouples are provided at the inlet of heat transfer fluid into wax meltingvessel and the return line to solar collector. A temperature indicator is used to display the readings. A flow regulating valve is introduced in the inlet line to monitor and regulate the flow rate of heat transfer fluid.

The set up is not provided with tracking device. A fixed position with N-S orientation is followed. Dish collector is tilted by 11.224° from horizontal (0.87 × lattitude for lattitude < 25°).

NOMENCLATURE

C_{p_h}– Specific heat capacity of heat transfer fluid

dT - Temperature difference of heat transfer fluid

$\bar{I}_D$- Long-term average direct radiation

m_h– Mass of heat transfer fluid

P_{abs} – Rate of energy absorbed by the absorber

q_u - Useful thermal energy delivered

T_a- Ambient temperature

T_h- Temperature of heat transfer fluid

t - Time (seconds)

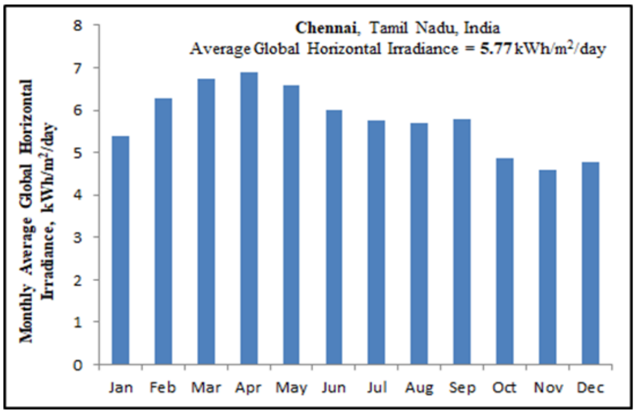

Figure 4 : Monthly Average Solar Irradiance in Chennai, Tamil Nadu, India

Sizing of the Parabolic Solar Collector

The heat demand load of the heater is such that it will heat about 15 litres of water, from ambient temperature to 100°C. However, in order to reduce space requirement, the heater will be designed in such a way that it will heat about 15 litres of water only at a time. Average uniform Solar insolation of the system ensures the heater for 4 cycles of almost full time length for heating the required quantity of water.

The absorber is a cylinder of outside diameter D_{abs}, internal diameter d_{abs}, height *l*, and thickness t = 2mm.

$$d_{abs} = \sqrt[3]{\frac{4V_h}{\pi}} \tag{1}$$

For solution of the equation in consideration with optimum design of the absorber the height *l* is made equivalent to the diameter d_{abs}.

$D_{abs} = d_{abs} + 2t$ (2)

The concentration ratio C is given as, A_a is aperture area and A_{abs} is absorber area

$$C = \frac{A_a}{A_{abs}} \quad (3)$$

The half-acceptance angle, $\emptyset$ is given by,

$$\emptyset = \mathrm{Sin}^{-1}\left(\sqrt{1/C}\right) \quad (4)$$

The optimum rim angle, ψ_{rim}

$\psi_{rim} = 90° - \emptyset$ (5)

The focal length, *f*, of the dish is obtained from

$$f = \frac{1+\cos\psi_{rim} \times D_a}{4\sin\psi_{rim}} \quad (6)$$

The height, h, of the dish is given by

$$h = \frac{D_a^2}{16f} \quad (7)$$

Sun's output = $\left[\frac{A_E}{S_s}\right]$ (8)

A_E= cross sectional area of the earth ;S_s = surface area of this imaginary sphere

$$R_c = I_{sc} \times AR_c \quad (9)$$

R_C = extraterrestrial radiation; A = land area and $\mathbf{I}_{sc}$ = Extraterrestrial solar constant

The heater absorber is of cylindrical one with outside diameter D_{abs}, internal diameter d_{abs}, height *l*, and thickness t = 1mm.

The containment volume of the cylinder is equivalent to storage volume of water, $V_h$available for heating and hence

$$V_h = \frac{\pi}{4} d_{abs}^2 \times l \quad (10)$$

For details of parameter estimations, see (Folaranmi J. 2009)

Performance Analysis of Dish Collector

The calculation of reflector area is obtained from full quantity of heat to boil the water completely in relation to the design insulation.

Heat, $q_1$required to be supplied to 1kg of heat transfer fluid,

$$q_1 = mC_{p_h}dT \quad (11)$$

Heat Loss Due to Free Convection on the Surface of the Absorber

From the top of the absorber

$$P_{Top} = a_t \left[\frac{KN_u dT}{h_a}\right] \quad (12)$$

Where a_t= Base area of the absorber, h_a= Height of the absorber, Nu = Nusselt number

For turbulence at the bottom of the absorber

$$Nu = 0.14\ \xi^{0.33} \quad (13)$$

The optical efficiency η_o is defined as the ratio of the energy absorbed by the absorber to the energy incident on the concentrator aperture

$$\eta_o = \frac{P_{abs}}{A_a \overline{I_D}} \quad (14)$$

The thermal efficiency of solar concentrator, $\eta_C = \frac{\text{energy delivered}}{\text{energy incident at the concentrator aperture}}$

$$\eta_C = \eta = \frac{q_u}{I_b A_a} \quad (15)$$

Energy Balance of the Collector

For steady state circumstances, the following equations for an energy balance on the absorber plate are given.

$$q_u = A_{abs} I_{sc} - q_1 \quad (16)$$

$$I = I_{sc}\left(a + b\frac{n}{N}\right) \quad (17)$$

a, b - climatic constants for a particular location

n - day of the year

N - Possible maximum insolations in a day.

The estimated containment of energy per cycle of the designed solar dish collector is given by

$$q_u = m_h C_{p_h}(T_h - T_a) \quad (18)$$

and $m_h = \frac{\rho_h v_h}{t}$ (19)

Dish Collector Dimensions		Trough Collector Dimensions
Inside diameter of absorber =275 mm		Length of the collector = 1065mm
Height of absorber = 270 mm		Parabolic diameter = 711mm
The optimum rim angle ψ_{rim}= 71.57°		Parabolic width = 750mm
The height, h, of the dish = 301mm		Outside diameter tube receiver = 25mm
The focal length, *f*, of the dish = 579mm		Inside diameter tube receiver = 19mm
The aperture diameter, D_a= 1000 mm		Length of tube receiver = 1300mm

Experimental Procedure

The experimental set up is kept on the roof top of the laboratory building and exposed to sun. Reflector surfaces are cleaned. Clean water of sixteen litres is filled in the receiver and closed leak proof. After the collectors are exposed to sun for an hour, the pump is started and the flow rate is set at 1.5 litres per minute. Wax vessel of 1.25 litres is filled with paraffin tablets. Every hour molten wax is drained out and weighed. Fresh charge is loaded periodically. Test trials are taken on July 21,2017 and August, 4,2017, two days from 9 A.M to 4 P.M. Molten samples of Paraffin wax were weighed and poured in to moulds for candle making. Figure 4. Displays the monthly average global horizontal irradiance in kW h/m^2/day in Chennai, Tamilnadu, India. The city lies 13.067lattitude and 80.24 longitude receives an average monthly global horizontal irradiance of 5.77 kW h/m^2/day, promising efficient solar installations.

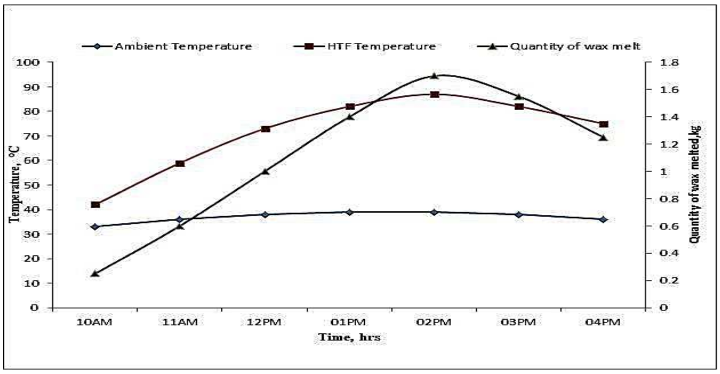

Figure 5: Time VS Temperature of Ambient, Heat Transfer Fluid and Amount of Wax Melted – Graph –July, 21, 2017

RESULTS AND DISCUSSIONS

Temperatures of water (heat transfer fluid), ambient temperature were recorded everyhour by the thermocouples coupled with temperature indicator. After summer period months of July and August, the testing was conducted. Amount of wax melted in kgf were also monitored. Against each hour from 9 A.M to 4 P.M, the temperatures recorded and weight of wax melted was plotted as graphs. Figure 5. depicts the hourly temperatures of ambient varies from a minimum of 29° C to a maximum of 39° C and the temperature of heat transfer fluid, water attains a peak of 87° C and a least of 32° C. The quantity of wax melted in the wax vessel by heat transferred from water to paraffin by convection and conduction mode.

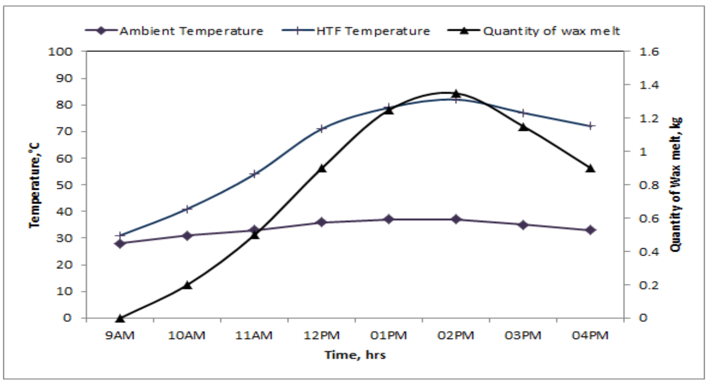

Figure 6 : Time VS Temperature of Ambient, Heat Transfer Fluid and Amount of Wax Melted – Graph –Au, 04,2017

The average temperatures on August, 04, 2017 shown in figure 6 were comparatively marginally less as sea breeze set by afternoon make the ambient cool rapidly. With the south facing fixed position, the harnessing of radiation

energy a slight increase in exit temperature of water can be obtained from the test model. It is because of the lower radiation losses. On the other side, more paraffin wax is melted as there is a remarkable gain in heat with the increase in the exit temperature of heat transfer fluid, water. When the flow rate of heat transfer fluid is increased 2 liters per minute, temperature difference between the inlet and exit points are declining leading to decrease in heat transferred. Hence 1.5 litres per minute is advisable for effective heating of heat transfer fluid.

CONCLUSIONS

The combination of parabolic dish and parabolic trough collectors with light weight and simple constructional set up had shown effective application of melting paraffin wax with melting point 62° C. Polished aluminium reflecting material concentrate most of the solar radiation effectively with less losses of heat transfer and is found obviously with the wax melting application. With fixed and north- south axis positioned parabolic collectors performed quite well. With various factors influencing their performance, the construction was simple, but the combined performance maintained effective functioning. Incorporation of a suitable phase change material augmented thermal energy stored in this set up may further enhance the performance and that is the future improvement.

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